

# **COST ESTIMATING AND RISK - MANAGEMENT FOR UNDERGROUND PROJECTS**

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**ABSTRACT:** This paper gives examples of cost estimation problems for large, complex infrastructure and underground projects, compares differing cost estimating approaches for two such projects and describes a cost validation and risk elicitation/identification process recently developed by the Washington Department of Transportation (WSDOT) with the author and colleagues. The paper builds on previous papers (e.g. Reilly & Brown, 2004) which described the cost estimation problems and proposed a suggested solution which was subsequently implemented by WSDOT in its Cost Estimate Validation Process (CEVP®). Recommendations are given for those owners of complex projects who wish to know a “more realistic probable cost” for their projects.

## **THE COST-ESTIMATION PROBLEM**

The public is skeptical of our ability, as a profession, to accurately estimate (i.e. predict) the final costs of large, complex public projects and also of our ability to manage these projects to established budgets. The public asks us:

- “Why do costs seem to always go up?”
- “Why can’t the public be told exactly what a project will cost?” and,
- “Why can’t projects be delivered at the cost you told us in the beginning?”

Our inability to answer these questions consistently is a consequence of many factors – principally an inadequate analysis and correction of poor cost estimating practices (Flyvbjerg et. al. 2002, 2003). Additionally, poor project management and poor communication with the public further adds to the problem.

The number of high-visibility projects where it appears to the public and the media that costs are “running away” or “out of control” seems to be increasing – and the cost increases involved are large.

Examples include the Jubilee Line Transit Project in London – 2 years late and £1.4 billion (67%) over budget (the budget which was communicated at time of decision to proceed); the Channel Tunnel - £3.7 billion (80%) over budget; Denmark’s Great Belt Link – 54% over budget; the 2003 Woodrow Wilson bridge tender in Virginia – 72 % over estimate and, Boston’s Central Artery Project – billions over the initial budget and years late (Salvucci, 2003).

As will be discussed later, early identification and management of risk is a key to meeting cost and schedule for large, complex underground projects (Arup, 2000).

One study (Reilly & Thompson, 2000) found that specific, relevant project cost information was usually unobtainable. Little objective history could be found, including findings that would support recommendations for improvement. Because of the difficulty in obtaining hard data, firm conclusions could not be reliably drawn, but the following findings were reported by owners:

- There are significant cost and schedule overruns suggestive of poor management in at least 30%, and possibly more than 50%, of the projects.

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- It appears that the factors that most directly influence success or failure are a) expertise and policies of the owner and b) procurement procedures.
- The professional teams engaged in projects were judged to be competent, by the owners, leading to the conclusion that problems in poorly performing projects may lie primarily with the ability of the owner to lead and manage the project process.
- Risk mitigation was not well-understood or applied, even in elemental ways. This was considered to be a promising area for development, in particular as it related to cost over-runs and unforeseen events.
- Reported cost and performance data – especially for “good” results – should be treated very cautiously. Consistent, complete and relevant data are very hard to get and almost impossible to validate after project completion.
- Conclusions based on reported cost data, unless the conclusions are grossly evident (e.g. meta-findings), should also be treated with caution.

Other studies confirm the problem. One study (Flyvbjerg et. al. 2002) surveyed 258 projects spanning 70 years and found that the problem of accurate cost forecasts has been chronic for that time period.

Moreover, as an industry, planning, design and construction professionals, and owners, have not corrected the chronic underestimation of the real cost of infrastructure projects. If they had done so, there would have been a uniform number of results over budget as under budget. They concluded that the problem is both an inability to estimate accurately, and also a bias to estimate on the optimistic side.

Fundamental issues underlie the cost estimation problem. The ultimate consequence is a rejection of public funding for projects - such as rejection of new taxes for highway projects in Washington State and Virginia, both in 2002.

## **COST ESTIMATING – TWO BOSTON EXAMPLES**

Two projects from the Boston area illustrate different aspects of cost estimating – and also that not all projects fail in this respect. From the public’s point of view, the Central Artery and Tunnel Project (CA/T) and the Massachusetts Water Resources Authority (MWRA)’s Boston Harbor Cleanup Program (BHP), were at the extremes of project performance – with respect to the cost estimates:

1. The CA/T Project was initially presented in 1986 as costing under \$3 billion. But this number did not correspond to the actual project, as constructed, with respect to scope, complexity and time. In 1990, as construction was about to begin, the “official” estimate was \$6 billion (Salvucci, 2003). Three years later it was “\$7 billion, not more than \$9 billion” (Leidon, 1993). The project will ultimately be delivered in 2005 at more than \$15 billion.
2. The Boston Harbor Cleanup Project initially presented a cost range of \$4 to \$4.9 billion. In 1992, at a very early stages of construction, a thorough review of the project cost was performed and the estimate was changed to \$3.65 billion. The project was delivered a decade later for \$3.8 billion. This is considered a cost estimating and project management success.

Among the many differences in these two projects are the way that the original estimates were prepared and presented – which dramatically affected the initial cost estimate – and, the “number” that the public remembers to this day.

1. The CA/T costs were in 1986 dollars with no escalation or contingency (consistent with FHWA requirements at the time) and the costs did not include provision for additional scope elements or all of the necessary “soft” costs.
2. The BHP estimate was built from estimated costs for the projected final program. It included contingencies and escalation to the projected mid-point of construction and it included all anticipated scope and “soft” costs envisioned.

Each project cost estimate was different – in scope, context and timeframe – and was being used, and understood, differently for each agency. However, the public – and the media – never understood these major



differences. The majority of the “public” had, and still has in the case of the CA/T, no knowledge that the numbers represented two completely different scopes, contexts and timeframes. For the CA/T the media has (unreasonably) continued to use the incomplete 1986 number as the basis of comparison in every discussion of cost on the program. Therefore, public opinion has been shaped, and mis-informed, by these poorly understood cost numbers.

## **COST-VALIDATION - MWRA’S METROWEST TUNNEL**

Another example from Boston illustrates how cost estimating procedures can be changed to improve cost estimating practice. MWRA became concerned that the estimated project costs for the MetroWest Water Supply Tunnel were significantly underestimated and so a critical review of the cost estimate, and the cost estimating procedures, was initiated.

A intensive review of the design team’s estimate was done by a group of independent professionals with project management, design and construction experience. The group included persons with specialized experience in estimating and constructing this type of project, viewed from a contractor's perspective.

The result was a revised cost estimate that included all costs including planning, design, permitting, compliance, land costs, mitigation costs, construction management, contingency and construction costs – all escalated as appropriate.

This new cost estimate was used in all subsequent public discussions. MWRA delivered the MetroWest Tunnel Project on schedule and under the approved budget and, in doing so, demonstrated a cost-validation process that was reasonable and which corrected an early, inadequate cost estimate.

The MWRA’s experience in critical cost review and its revised cost estimating approach became one of the three critical foundations of WSDOT’s Cost Estimate Validation Process - CEVP<sup>®</sup>.

## **WSDOT EVALUATES COST ESTIMATING PROBLEMS**

In 2001, WSDOT was looking at a large highway construction program, of the order of US \$30 billion. The cost estimating and communication problems, cited above, led the Secretary of Transportation to ask for:

- 1) a critical evaluation of the problem and
- 2) development of a better cost estimating methodology.

Findings included the following:

1. There is a general failure to adequately recognize that an estimate of a future cost or schedule involves substantial uncertainty (risk).
2. The uncertainty must be included in the cost estimating process.
3. Costs, especially construction costs, must be validated by qualified professionals, including experienced construction personnel who understand “real-world” bidding and construction.
4. Large projects often experience large scope and schedule “changes” which affect the final cost. Provision for this must be made in the cost estimates and management must deal competently with these changes.

WSDOT decided to address these findings by:

1. Using an improved cost estimating methodology,
2. Incorporating cost validation and uncertainty,
3. Communicating “ranges of probable cost” to the public, media and key political decision makers.

Essential elements of the new process included an external review by independent, professionals, including “validation” of base cost and schedule estimates and assumptions, replacing “contingencies” (which are allowances for unknowns) with explicit cost and schedule uncertainty (risks and opportunities). A key objective was to move from “single value” cost estimates to cost estimates which are communicated as “ranges of probable cost”.



## THE WSDOT COST ESTIMATE VALIDATION PROCESS (CEVP<sup>®2</sup>)

Accordingly, in January 2002, the WSDOT Secretary of Transportation tasked small group of consultants and WSDOT managers to develop a new cost estimating procedure. The result was WSDOT's Cost Estimate Validation Process - CEVP.

### CEVP

CEVP develops a probabilistic cost and schedule model to comprehensively and consistently define the probable ranges of cost and schedule required to complete each project. The basic approach requires a peer-level review, or “due diligence” analysis, of the scope, schedule and cost estimate for a project and then to incorporate uncertainty (uncertainty includes both risk and opportunity) to produce a range of probable cost and schedule.

Specific objectives of the method are to evaluate the quality and completeness of “base costs” together with the inherent uncertainty in the estimate.

The results of the assessment are expressed as a probable distribution of cost and schedule values for the project (Figures 1 and 2). In summary (Reilly et. al. 2004), the CEVP process:

1. Critically examines the Project estimate to validate all cost and quantity components using independent external professionals.
2. Removes all “contingency” and allowances for unknowns.
3. Replaces contingency and other approximating allowances with individually identified and explicitly quantified uncertainty events (risks plus opportunities).
4. Builds a model of the project – normally in an Excel spreadsheet – from a flow-chart of key planning, design, permitting and construction activities. Included are quantification of cost and critical path schedules. The model assigns the quantified uncertainty events to activities with the associated probabilities and impacts.
5. Runs a simulation to produce the projected “range of probable cost and schedule”.
6. Report the results (Figure 1).

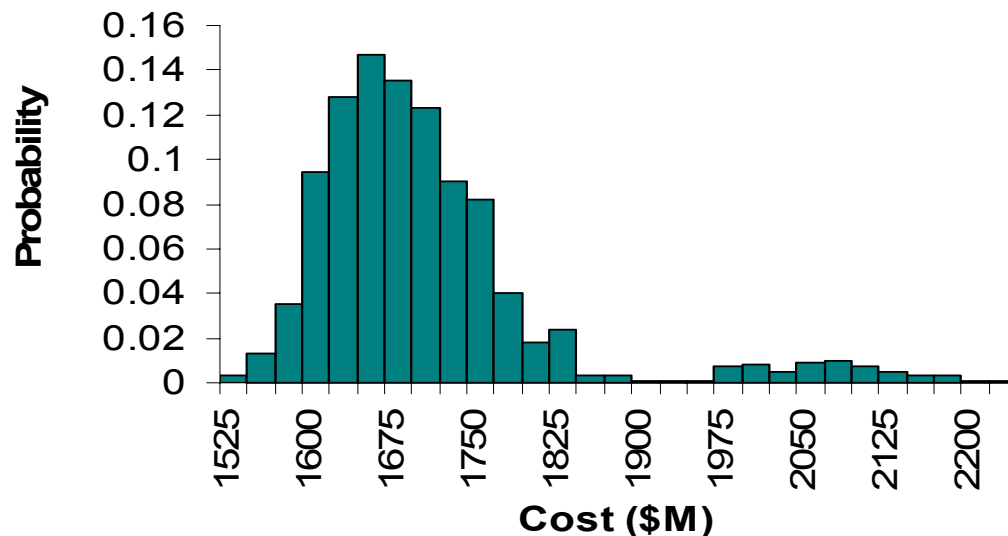


Figure 1 – Future costs are a “range of probable costs”

<sup>2</sup> CEVP<sup>®</sup> is registered to the Washington State Department of Transportation to recognize its development and application of this new process and to assure that, if the process is applied by others, that they acknowledge WSDOT and follow the basic requirements of the process. Hereafter CEVP will be used in the text.



## **CEVP WORKSHOP**

Two key elements of the CEVP process are cost validation and risk elicitation (the third required element is the subsequent communication of results to the public and political decision-makers).

Because the CEVP process has been described previously in several papers (Reilly & Brown 2004) this paper will detail two core processes – cost validation and risk identification.

## **CEVP - COST VALIDATION**

The CEVP Team consists of the project team and the CEVP specialists working closely together since it is critical that the results of the CEVP process are understood and “owned” by the project team.

The CEVP cost workshops are led by a manager with program delivery experience, supplemented by CEVP team members with both design and real-world construction experience. The use of personnel with experience in contractor's methods is necessary to bring that perspective into the cost review for a well-shaped determination of “base cost” – the cost if “all goes as planned and assumed”. The process consists of the following:

1. The project team first briefs the CEVP specialists on the detailed scope of the project and identifies cost and schedule risks that have been included in the project estimate.
2. The CEVP cost specialists discuss the cost estimate with the project team, reviewing what the estimate represents and the basis of its development. They discuss what metric has been used to calibrate the estimate and what contingencies have been included in the estimate.
3. A review of the scope of the project is completed with the project team on an element by element basis to assure that all elements and phases of the project have been accounted for.
4. The estimate is reviewed to assure that items such as: right of way, mobilization, permitting, mitigation, temporary facilities and utilities, construction phasing requirements, seasonal constraints, cuts/fills, hazardous material issues, archaeological issues, storage and disposal of material, haul distances, compaction and testing, protection of work, testing of mechanical and electrical systems, occupancy permits, de-mobilization, etc. have been recognized and addressed – from a cost standpoint.
5. The schedule for the project is also reviewed - is it realistic?, does it consider adequate time for mobilization?, set-up of temporary facilities and utilities?, construction permitting?, construction phasing?, dealing with differing site conditions?, traffic or operational issues?, seasonal constraints?, site access limitations?, testing of piping?, electrical and signals?, SCADA systems? etc..
6. Unit prices and production rates that have been assumed for the major items of work are reviewed, asking if the production numbers (the basis of the units costs) are reasonable and if there are any risks that those unit prices may not have taken into account – such as high ground water or the presence of organic material.
7. The contingency that is included in each unit price – or the entire estimate – is identified and removed from the cost estimate. This is done in order to develop the “base cost” of the project (the contingency is subsequently replaced by the probable cost of risk and opportunity events).
8. During the discussions, and upon completion of the above review, items of work that may be missing, over- or under-estimated are identified and recorded. Estimates for missing items are developed and recommendations for adjustments are made. Finally, an agreed “base cost” is determined. This becomes the base to which the cost of potential risk and opportunity events are added by the cost/schedule uncertainty model.



## **CEVP - RISK IDENTIFICATION AND ELICITATION**

The risk part of the CEVP workshops are led by an experienced risk elicitor (risk analyst) who is familiar with uncertainty theory, de-biasing techniques and the structure of a subsequent cost and risk model.

Other workshop participants include representatives from the project team who have familiarity with the plans, strategies, assumptions and constraints on the project, plus subject matter experts (SME's) who bring an independent perspective on important areas of project uncertainty.

The identification and quantification of uncertainties requires a balance of project knowledge, risk analysis expertise, cost estimating expertise, and objectivity. Project knowledge and the independent expertise of SME's are essential to identify the uncertainties. Risk analysis expertise is required to capture balanced information on risk and model uncertainties. The risk workshop preparation includes the following activities:

1. Appropriate (but limited) training of participants in the principles and procedures of uncertainty (risk and opportunity) assessment
2. Preliminary work to capture the plan and strategy of the project in a draft "flowchart",
3. A preliminary list of risks and opportunities,
4. Identification and validation of base costs (as described previously)

The goal of the risk workshop is to identify, quantify and model the uncertainty in project cost and schedule. The principal activities are:

1. Identification of potential risks and opportunities. This is done in an open brainstorming process that typically begins with a prior list of potential uncertainties from the project team, lists from similar projects and other sources. In the workshop, it is necessary to provide a critical environment that allows for this initial information to be combined with other suggested risks. As a practical matter, the team should identify a screening criteria to help produce a prioritized list of significant cost and schedule risks.
2. Characterization of potential risks and opportunities. This process combines subjective and objective information to identify the consequences to the project if each of the risks were to occur. Typically there are varying opinions on the range of consequences, such as increased cost or schedule delay. The risk elicitor is responsible for guiding the group to an appropriate agreement regarding the consequences of the risks – i.e. probability of occurrence and impact. Independence and correlation among risks is also defined, positively or negatively.
3. Analyzing the risk information and base costs.

The risk and opportunity events that are the output of the workshop should be defined to be independent as far as possible. When this is not possible, the dependencies among events must be defined and accounted for. In addition, each risk or opportunity event must be allocated to the project activities that are affected by it or, if a given event affects multiple project activities, significant correlations among occurrences need to be addressed. Significant uncertainties and correlations among event impacts also need to be defined. This information is incorporated in the cost and schedule to produce the model results.

Risk elicitation within CEVP is an iterative process that must combine subjective and objective information. Uncertainty characterizations and probabilities are defined simultaneously to provide reasonable, practical descriptions of uncertainty.



## COMPLETION OF THE CEVP PROCESS

The project's "range of probable cost and schedule" is determined by combining the base costs determined from cost validation and the risks plus uncertainties identified from the risk workshop in a model which:

1. Integrates base costs with risks and opportunities (uncertainties) in a probabilistic model
2. Reports the CEVP results as a "range of probable cost and schedule"

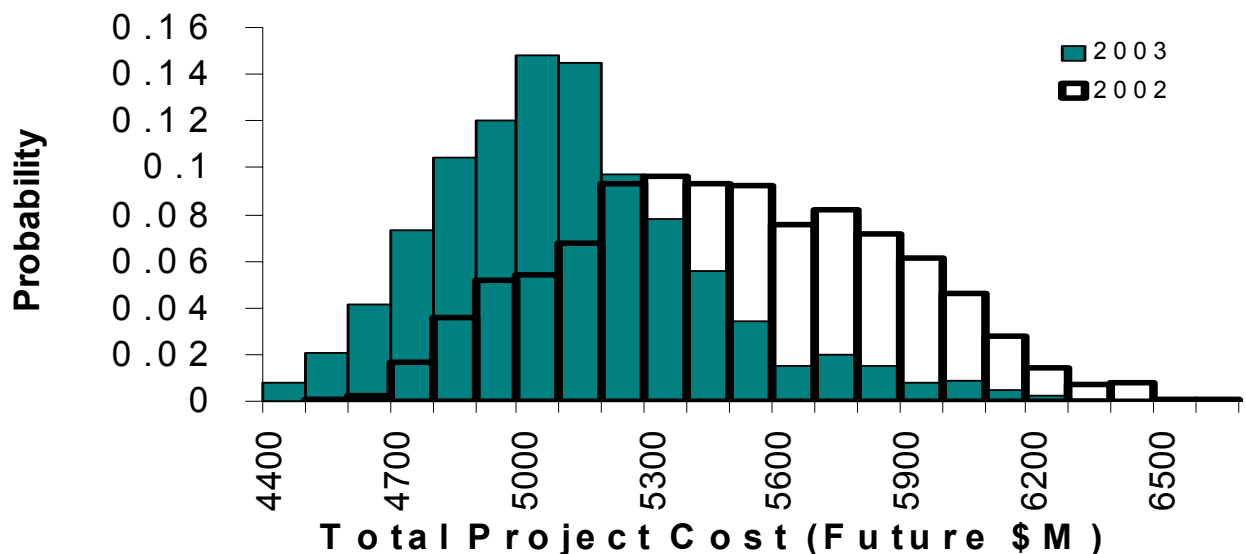
Results of the model analysis are presented as cost and schedule probability distributions, usually in a graphical form (Figure 2) with supporting tabulations of characteristic statistics. First order descriptions and models are sufficiently accurate and are used for most projects. These distributions can describe a variety of situations of interest including:

1. Current dollar (time of assessment) cost and year of expenditure cost (\$YOE)
2. Fully funded or partially funded scenarios
3. Comparative design options
4. Probable date of completion for the project
5. Probable schedule to meet project milestones

The specific form of the reported results can vary depending upon need and the results can be used for a number of applications, including:

1. Project assessment / management re-direction
2. Risk management plans
3. Data input to value engineering workshops
4. Integrated management of multiple projects
5. Better internal and external communications
6. Financial management options and alternatives

CEVP is iterative in nature. For many project applications it is appropriate to conduct a reassessment of the project from time to time to update project changes, cost and schedule estimates. The following example of 2003 results compared to 2002 results for a complex highway project in Seattle, shows a reduction in both probable cost and uncertainty (range):



**Figure 2** – Improvement in probable cost (mean and distribution), successive CEVP workshops, Alaskan Way Project.



## CURRENT DEVELOPMENTS

CEVP is proving to be a useful process for estimating and communicating ranges of probable costs and schedules, as well as explicitly identifying and quantifying risks, for large, complex projects early in the planning and design phases. There is better information that the public, and elected officials, can use to make sound decisions and that engineers can use to better manage their projects.

WSDOT has internalized the process and uses it, and a simpler “Cost Risk Assessment” process, for many of its projects

The U.S. Federal Transit Administration and the Federal Highway Administration have each investigated the CEVP results. They have concluded that CEVP, or a similar process, should be used for large, complex projects. As of this writing further demonstration projects and educational seminars are underway and WSDOT has been designated “Lead Agency” status in this work.

## FINDINGS

1. WSDOT found that CEVP focuses early attention on the significant cost and schedule risks for a project and increases the project team’s awareness of risk.
2. Use of experienced external subject matter experts, who have constructed similar projects, is good value and gives an independent check on key assumptions.
3. Because risks are explicitly defined, a risk management plan (Grasso et. al. 2002) can be quantified earlier. This allows significant management and control of cost and schedule earlier in a project (Arup 2000) and allows a more explicit communication of cost and schedule (and changes thereto) with the public and key political decision makers.
4. WSDOT found that CEVP permitted a more intuitive communication with the public which better related to “...what people already know”.
5. WSDOT recognized the value that cost validation and risk assessment provides.
6. WSDOT recognized that CEVP is not a “magic bullet” or a “quick fix”. WSDOT therefore committed to improve its cost estimating process by implementing the CEVP program on a state-wide, long-term basis and training staff in the technique.

## RECOMMENDATIONS

1. Owners of complex infrastructure and underground projects should consider using a WSDOT CEVP type process for early cost validation and risk identification.
2. Such a process leads to an explicit, quantified definition of potential risk events – this becomes a basis for a quantified risk management plan for each project.
3. Periodic updates to the model can be used to assist with, and explain rationally, project changes. They can, additionally, evaluate and compare alternatives.
4. Such a process has promise to assist owners in determining a more realistic “range of probable cost” which can enable better communication about, and management of, these projects.
5. This is only possible if the owner truly wants to know the realistic “range of probable costs” and is prepared to communicate this to the public and decision makers.
6. It is recognized that significant concerns have been raised that, if we tell the public the more realistic probable costs, which tend to be greater than other estimates, projects will never be funded and authorized. Such concerns imply that we cannot trust the public with the real cost information. If true, such a position has moral implications that the profession needs to address.



## ACKNOWLEDGEMENTS

The WSDOT project teams and CEVP consultants rose admirably to the challenge of implementing a new process which questioned established ways of cost estimating. It required a high-level of dedication and persistence to develop and implement the new process and then report the CEVP results, for 10 mega-projects, in only 4 months.

The CEVP process, and its successful application, would not have been possible without the commitment and expertise of the following personnel: WSDOT - Secretary MacDonald, John Conrad, David Dye, Cliff Mansfield, Jennifer and Adam Brown, Monica Bielenberg; MWRA - Michael McBride; Consultants - John Reilly, Bill Roberds, Dwight Sangrey, Travis McGrath, Keith Sabol, Art Jones, Richard Rast, plus Paul Silvestri and his National Constructors Group; University of Colorado - Keith Molenaar & Jim Diekmann; plus, many others who have been, and are now working on, these projects and this process.

## REFERENCES :

1. Arup 2000, London Jubilee Line, Secretary of State's Agent (Arup), "End-of Commission Report", July.
2. Flyvbjerg, B.; Holm, M., Buhl, S. 2002 'Underestimating Costs in Public Works, Error or Lie? American Planning Association Journal, Vol. 68, No. 3
3. Flyvbjerg, B.; Bruzelius, N. & Rothengatter, W. 2003 'Megaprojects and Risk: An Anatomy of Ambition' Cambridge University Press, March, 208 pages. ISBN: 0815701284
4. Grasso, P., Mahtab, M., Kalamaras, G. & Einstein, H. 2002, 'On the Development of a Risk Management Plan for Tunnelling', Proc. AITES-ITA Downunder 2002, World Tunnel Congress, Sydney, March
5. Leidon, C. 1993 "The Connection – Central Artery Project" National Public Radio Broadcast, Boston
6. Reilly, J. & Thompson, R. 2001 'International survey, 1400 projects', internal report.
7. Reilly, J. 2003, "Towards Reliable Cost Estimates", Tunnels & Tunneling, North American Edition, September, Viewpoint Article, p4
8. Reilly, J. & Brown, J. 2004 "Management and Control of Cost and Risk for Tunneling and Infrastructure Projects" Proceedings, World Tunneling Conference, International Tunneling Association, Singapore, May
9. Reilly, J., McBride, M., Sangrey, D., MacDonald, D. & Brown, J. 2004, "The development of CEVP® - WSDOT's Cost-Risk Estimating Process" Proceedings, Boston Society of Civil Engineers, Fall/Winter
10. Salvucci, F. 2003 "The 'Big Dig' of Boston, Massachusetts: Lessons to Learn", T&T North America, May.
11. WSDOT CEVP Website <http://www.wsdot.wa.gov/projects/projectmgmt/riskassessment>